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Adaptation and Performance Evaluation of Engine-Driven Coffee De-Huller

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ABSTRACT

A simple and low-cost de-huller powered by a 5-horsepower diesel engine that can be used to de-hull dry coffee materials was adapted. The coffee de-huller machine was evaluated at different drum and feeding rates on the farm. The results obtained show that the de-hulling efficiency, percentage of breakage, and cleaning efficiency increased as the drum speed increased between 400 and 600 rpm. The highest averages of de-hulling efficiency, cleaning efficiency, percentage of breakage, and capacity were 97.34%, 98.77%, 3.18%, and 358.7 kg/hr, respectively. High de-hulling and cleaning efficiencies and a low percentage of breakage obtained show that the machine is very appropriate for handling coffee processing.

Keywords: Coffee; Percentage of breakage; De-huller efficiency; Cleaning efficiency; De-hulling capacity; Cost analysis; Break-even point.

1. Introduction

The farming of coffee is crucial to the Ethiopian financial benefits, either directly or indirectly employing more than fifteen million people. Coffee is Ethiopia's most important export commodity, accounting for 41% of total foreign exchange revenues and roughly 10% of GDP [1]. Coffee supports more than a quarter of Ethiopia's population, or 15 million people [2]. This includes 8 million people directly involved in coffee production as well as 7 million people employed in the processing, commerce, transportation, and financial sectors [3], [4].

Over 1 million small-scale farmers with an average farm size of 0.5ha produce more than 95% of Ethiopian coffee, with state-owned plantations accounting for 4.4% and private investor plantations accounting for 0.6% [5]. The quality of Ethiopian coffee is determined by two key factors: its geographical location and the processing following harvest procedures [5]. Coffee quality is estimated to be determined at 40% in the field, 40% after harvest, and 20% during secondary/export processing and handling, including storage. To improve the quality and market value of Ethiopian coffee, improved primary processing by farmers at the village level is required.

A rise in coffee quality, and hence income, has a direct impact on the livelihoods of a large number of rural people with limited resources. In the 2015/16 Meher Season, Oromia National Regional State obtained 417,557.38 ha of land, and 2,586,654.70 quintals were produced with an average yield of 6.19 quintals/ha (CSA, 2016). Arsi Zone, along with Chole, Aseko, Merti, Guna, and Gololcha, is one of the Oromia region's coffee-producing zones, but only Gololcha coffee is recognized on the national market [7]. Aside from these woredas, the districts of Seru and Shan Kolo hold great promise. During the 2015/16 Meher season, 6,476.56 ha of land was allotted, and 40,248.25 quintals were produced, with a yield of 6.21 quintals/ha on average.

Even though many farmers produce coffee, they are limited by processing technologies such as coffee de-hullers. Bako Agricultural Engineering Research Center and Jimma Agricultural Engineering Research Center were involved in creating, demonstrating, and introducing the technique to overcome this problem. The BAERC designed and tested a 251.7 kg/hr engine-driven coffee de-huller with a de-hulling efficiency of 93% [8]. The

JAERC also built and tested a manually operated dry bean coffee de-huller with capacities and de-hulling efficiencies of 81 kg/hr and 96% [9]. However, due to a lack of availability and farmer understanding, this machine was not employed by farmers. It was also not examined or demonstrated in the area. This could be due to the high level of work necessary in the physical de-hulling of coffee for home consumption and sale, resulting in lower quality. As a result, it was thought acceptable to create a machine that could handle the problem highlighted above to reduce problems related to coffee de-hulling. As a result, the goals of this study would be to modify and assess the performance of the Bako Agricultural Engineering Research Center coffee de-huller machine.

2. Materials and Methods

In this particular paper, an attempt has been made on the farm to evaluate coffee de-huller. The designed and developed de-huller machine at Bako-Agricultural-Engineering-Research Center was brought and tested on the station against their respective technical specification.

The operators performed the entire test based on the recommended de-huller test format. After the test on the station, some modifications were made to the parts so they could be better manufactured for the full package performance evaluation of the de-huller machine. Then the site and farmer selection were done based on the potential area of coffee farming in the Arsi-zone, Gololcha, and Chole-districts. Then, adapting and evaluating the machine were done accordingly.

2.1. Machine Description

The overall length, width, and height of the machine were 152, 93, and 133 cm, respectively. The machine consisted of the following major components: (1) hopper; (2) drum; (3) frame; (4) power transmission assembly (belt and pulley); and (5) cleaning system (fan and sieve). Figure 1 shows the evaluated machine used on the farm. The specifications of materials and dimensions for machine components are mentioned in Table 1 in detail.

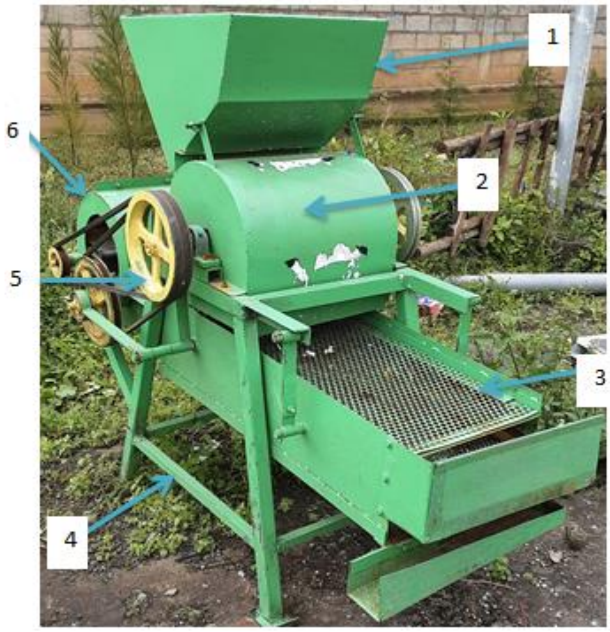

Figure 1. The pictorial picture of the coffee de-huller (1. Hopper, 2. Drum, 3. Sieve, 4. Frame, 5. Pulley, 6. Fan)

Table 1. Materials specification and dimension of machine components

Specification	**Dimensions**
Double line Drum Pulley for fan and eccentric	25.5 cm
Eccentric Pulley	25.5 cm
Eccentric Diameter	8 cm
Fan Pulley	9 cm
Pulley on the engine shaft	8 cm
The pulley on the drum, which is attached to the engine with a single single-line	28 cm
Sieve 12,10 ,6 mm diameter	40 x 92 cm
Bearing (P206)	#2
Bearing (P204)	#2
Shaft 30mm diameter for drum	93 cm
Shaft 20mm diameter for fan and eccentric	93 cm

Hopper: The container that feeds the de-hulled coffee directly to the de-hulling devices. The structure would be done with 1.5 mm thick sheet metal.

Drum: The de-hulling drum pulverized and released the coffee bean. It is composed of a circular plate with a diameter of 40 cm and a length of 40 cm that is punctured in the center to enable a shaft with a size of 30 mm for passage through.

Cleaning unit (Fan and sieve).

Fan: The fan was made of straight sheet metal that was welded to a shaft inside a casing. For increased blowing efficiency, the blower shell might be spirally formed.

Sieves: To separate de-hulled and un-de-hulled coffee, three-stage sieves were utilized. The sieve hole was oval and 12mm long, depending on the major mean diameter of the coffee seed.

The frame: It is what holds the entire machine together. It is a trapezoidal-shaped structure composed of a 40*40 mm square bar with a stipulated minimum frame length ratio of L1/L2 = 0.5, as described in [8]. This was done to increase stability and make transportation easier.

2.2. Working principles

A 5-horsepower diesel engine powers the de-huller, which rotates the drum via a pulley and belt system. The coffee bean was manually fed into the machine via a hopper. The de-hulled coffee falls into the de-hulling unit by gravity through the hopper, and the feeding rate is set by the control gate.

2.3. Performance evaluation

The machine's performance was evaluated using the following equation: the parameters are de-hulling capacity and efficiency, cleaning efficiency, and percentage of breakage.

$$\text{Ca (kg/hr)} = \frac{M_T}{t} \qquad (1)$$

$$\text{PB (\%)} = \frac{M_T}{M_{ud} + M_b} * 100 \qquad (2)$$

$$\text{CE (\%)} = \frac{M_t - M_c}{M_t} * 100 \qquad (3)$$

$$\text{DE(\%)} = \frac{M_t}{M_t + M_{ud}} * 100 \qquad (4)$$

Where,

Mt = total mass of de-hulled coffee (kg), T = de-hulling time (hour), M_{ud} = weight of un de-hulled coffee (kg), M_{ub} = mass of unbroken coffee (kg), M_b = mass of broken coffee (kg), Mt = total mass at the outlet (kg), and Mc = MOG at the main outlet (kg).

2.4. Estimation of Fuel consumption

The first de-huller machine was kept on a level surface to calculate fuel consumption. The fuel tank had been filled before the test. The motor was shut off after the de-hulling procedure was completed, and the tank was replenished to its original level. A graduated measuring cylinder was used to determine the amount of fuel in the tank. Fuel efficiency was calculated using the difference in fuel consumption before and after de-hulling.

2.5. Cost analysis of the coffee de-huller

A simple cost study was carried out for the coffee de-huller. The actual cost, annual fixed cost, and variable expenses of the gadget were all examined. The annual fixed expense includes depreciation, interest, and shelter costs. Maintenance and repairs expenses, labor costs, and electricity expenses were all variable expenses. The interest rate was considered to be 13%, the cost of shelter was 0.01% per year, the cost of repair and maintenance was 0.01% per hour, the operation each day was 8 hours, the yearly use was 700 hours, and the machine life span was determined to be 7 years. The cost was calculated using the following formulas: The following is how the annual depreciation was calculated:

$$D = (P - S)/L \qquad (5)$$

Where D denotes depreciation, P is the machine's purchase price, S is the salvage or selling price, and L is the interval between buying and selling.

And, Interest was determined as:

$$I = [P + S/2] \times i \qquad (6)$$

Where I is the expected return on capital; P is the machine's purchase price; S is the salvage value or selling price; and i is the current rate of return on investment.

Total cost = Annual fixed cost + Variable cost (7)

In this study, the device's break-even point was studied, which is stated in terms of the amount of dry coffee required to de-hull every year. Equation 8 gives the device's break-even cost [10].

$$BEP = \frac{AFC}{CR - VC} \tag{8}$$

Where CR is the custom rate, AFC is the annual fixed cost, and VC is the variable cost.

2.6. Design of Experiments

The experiment was carried out in a factorial design with three replications, with drum speed and feed rate as treatments.

The treatments' specifics were as follows:

Three levels of RPM (400, 500, and 500) based on [8], [11], and three levels of feed rate (4, 5, and 6) kg/hr

2.7. Data analysis

For the analysis, Statistix 10 statistical software was employed. LSD was used to identify treatment means that differed at 5% significance levels. The F-test and analysis of variance have been utilized to calculate the degree of significance (P) for these associations.

3. Results and Discussion

Interims of de-hulling capacity (C), percentage of breakage (PB), de-hulling efficiency (DE), and cleaning efficiency (CE) of the coffee de-hulling machine performance were discussed.

3.1. De-hulling Efficiency

Table 2. Effects of drum rotation speed on de-hulling Efficiency and percentage of damage

Drum RPM	Percentage of Breakage (%) Feed rate (kg/min)			De-hulling Efficiency (%) Feed rate (kg/min)		
	4	5	6	4	5	6
400	0.89	1.1	1.89	96	94	93.66
500	1.01	1.4	2.2	97	95.67	95.19
600	1.23	2.3	3.18	98.03	97.81	97.34
Mean	1.04	1.6	2.42	97.01	95.83	95.39
CV		11			3.63	

The de-hulling efficiency was above 93.66 %, at 400 rpm of drum and the minimum average hulling efficiency achieved by each drum speed was over 93 % as showed Table 2. This indicates that shearing and impact force are

very important for de-hulling coffee, which agrees with the finding of [12] that the shearing mechanism is efficient for grains. The de-hulling efficiency increased with the increase in drum speed. The increase in efficiency may be proved by the fact that de-hulling by shearing and impact force increased due to an increase in drum RPM [13], [14], and [15] and had the probability of making more materials collide with one another, as earlier observed. The Anova Table 3 shows a significant difference at 5% levels among the drum speeds, which further confirms this. [13] also observed a significant difference in threshing grains at the 5% significant level using a similar mechanism.

ANOVA found that both main effects were statistically significant at the 5% level. The greatest de-hulling efficiency was 98.03% when the drum RPM was 600 rpm and the feeding rate was 4 kg/min, while the minimum de-hulling efficiency was 93.66% when the drum speed was 400 rpm and the feeding rate was 6 kg/min, and a similar result was discovered by [8].

Table 3. ANOVA Table of the test run

F – Value

Source of variation	Degree of freedom (DF)	DE	PB	Ca	CE
FR	2	305.36*	97.51*	4510.34*	284.15*
RPM	2	67.25*	168.06*	63.36*	65.6*
FR * RPM	4	22.66**	87.93**	26.71**	25.1**
Error	18				
Total	26				

*significant at $\alpha = 5$ %, **significant at $\alpha = 1$ %

3.2. Percentage of breakage

The percentage of breakage is proportional to the drum speed and feed rate, as shown in Table 3. The highest percentage of breakage, 3.18%, was discovered when the coffee was de-hulled at cylinder speed of 600 rpm and feed rate of 6 kg/min, while the lowest percentage of breakage, 0.89%, was discovered when the coffee was de-hulled at drum's RPM of 400 rpm and feed rate of 3 kg/min.

For drum speeds ranging from 400 to 600 rpm, the percentage of breakage ranges from 0.89 to 3.18 percent. According to 16, 15 increasing drum speed and decrease in moisture content increased percentage breakage somewhat increases drum speed increases the percentage of breakage [17].

This suggests that employing a de-huller with a high drum speed on coffee would result in a high proportion of breakage. In this case, it would be said that there was a low percentage of breakage.

Table 3 shows that there was a substantial difference in the percentage of breakage between the RPM of the drum and the feed rate at tested levels, demonstrating the machine's potential for producing quality coffee even at high feed rates and RPMs of the drum. The acquired results were validated by [18], who discovered that at the 5% level, the effects of Drum's RPM on the percentage of breakage were significant.

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3.3. Capacity of de-hulling

The maximum de-hulling capacity was 358.7 kg/hr at 600 rpm on the drum. In general, de-hulling capacity is proportional to the drum's RPM.

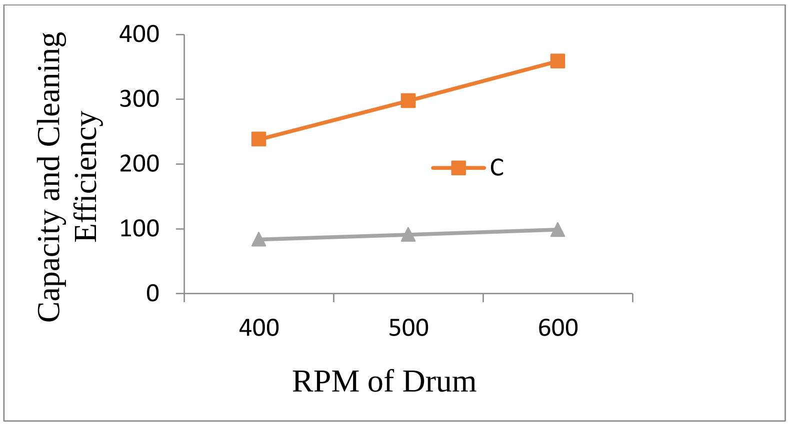

Figure 2. Effect of drum RPM on capacity and cleaning efficiency

3.4. Cleaning efficiency

As shown in Figure 2, increasing the drum's RPM from 400 to 600 rpm, which translates to increasing the fan speed from 1133 to 1700 RPM, enhanced cleaning efficiency from 83.57 to 96.77%. The results were consistent with [13], who showed that increasing fan speed improves cleaning efficiency. He also studied three distinct crops; fan speed had a positive linear connection with cleaning efficiency, with a coefficient of determination ranging from 0.93 to 0.97. Another scholar [19] further argued that grain conveyance on the sieve is influenced by air velocity, resulting in the initial distribution of grains from things other than grains. As a result, high fan speed may be stated to help clean coffee beans. As demonstrated in Table 3, the cleaning efficiency was significant at the 5% level and highly significant for the combination of feed rate and RPM. The results obtained were consistent with 13 observations that there was a substantial variation in fan speeds at the 5% level.

3.5. Cost analysis of coffee de-huller

Table 4 illustrates the Coffee de-huller's cost factors and products. The machine costs roughly 12518.68 ETB without the engine and 37518.68 ETB with the 5hp diesel engine. The fixed cost includes three cost items: depreciation, interest, and shelter, whereas the variable cost includes fuel, oil, labor, repair, and maintenance. Table 4 shows that the cost of the coffee de-huller was only 0.22 Birr/kg.

Table 4. The coffee de-huller machine cost variables and items

	Items/Variables	ETB
1	**Cost of coffee de-huller**	
A	Raw Material cost	8231.6
B	Materials wastage = 2.5 % of a	205.79
C	Production cost (machine + labor)	1389.33

D	Overhead cost = 5% of c	69.47
E	profit = 10 % of (a + b + c + d)	989.62
F	sell tax =15% of (a + b + c + d + e)	1632.87
G	selling price = (a + b + c + d + e + f)	12518.68
8	Engine cost (Assume)	25,000
	Total cost	**37518.68**
2	Life of the de-huller	7 yrs
3	Annual use	700 hr
4	Annual fixed cost	
	a. Depreciation	5627.8
	b. Interest (13 %)	2682.59
	c. Shelter (0.01 of P)	5.751
	Total	**8316.14birr/yr**
	Total	**11.88 birr/hr**
5	Variable cost	
	a. Repair and maintenance (0.01 % P)	3.75 birr/hr
	b. Labor (two labors, 150 ETB /day)	37.5 birr/hr
	c. Fuel (0.29lit/quint = 6.79bir/quintal)	23.75 birr/hr
	d. Oil (3 % of fuel)	0.71 birr/hr
	Total	65.71 birr/hr
6	**Total cost**	**77.59 birr/hr**
7	**Cost de-hulling (350 kg/hr)**	**0.22irr/kg**

3.5.1. Break-even point

According to Table 4, the coffee de-hulling machine has an initial cost of 37518.68 ETB and a life expectancy of 7 years. Under fundamental assumptions and current market practice, the average yearly fixed price of operating the machine was 8316.14 Birr. The following assumptions are made: 13% interest, 0.01% shelter per year, 0.01% repair and maintenance per hour, 8 hours of service per day, 700 hours of annual use, and a custom rate of 1.25 birr/kg. To recover the cost of construction, the coffee de-huller must de-hull 8 tons of dry bean coffee in one year. Figure 3 depicts the break-even point highlighted. If the available quantity of coffee to be de-hulled exceeds the break-even quantity, using the de-huller may result in a profit. Otherwise, the machine is costly to operate when the coffee to be de-hulled is less than the break-even number.

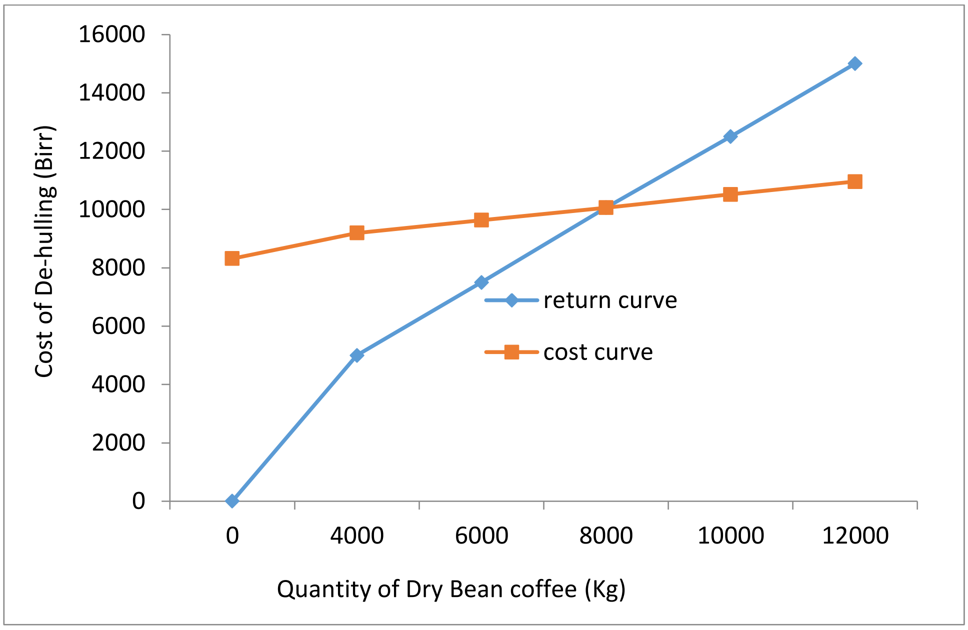

Figure 3. The cost of operating the de-huller and the quantity of dry bean coffee

4. Conclusion

The coffee de-huller is a simple, low-cost, and versatile prototype that uses a 5.0 horsepower diesel engine to de-hull dry coffee materials. The machine's drum RPM and feed rate were both influencing its performance. When the RPM of the drum was increased from 400 to 600, the throughput capacity increased from 238.8 to 358.7. As the RPM of the drum increases from 400 to 600, cleaning efficiency, percent of breakage, and de-hulling efficiency increase from 83.57 to 98.77, 1.89 to 3.18, and 93.66 to 97.34, respectively. The combined influence of RPM and Feed Rate was highly significant on all machine performance evaluation criteria.

4.1. Recommendations

The following recommendations are given in light of the findings:

Since the size of dry bean coffee is different (small, medium, and large), adjusting the control gate for the bigger size, the tendency of under-hulling of the smaller size was high, so the uniformity of de-hulling was not consistent.

When adjusting the control gate for the smaller size, the percentage of breakage increases; hence, for further improvement, the dry bean coffee must be graded and used.

By using this machine, de-hulling operations are possible, so the service provider can also use this machine, which could generate income for rural people.

Declarations

Source of Funding

This study has not received any funds from any organization.

Conflict of Interest

The authors declare that they have no conflict of interest.

Consent for Publication

The authors declare that they consented to the publication of this study.

Authors' Contribution

Abayineh Awgichew participated in the idea or design of the scheme, data gathering, analysis, interpretation, article drafting, article revision, and final approval of the manuscript. Rabira Nuguse helped with data gathering, article drafting, article revision, and final approval of the manuscript.

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